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Prediction of growing season rainfall and crop yields in southern Australia

Ian Holton
Holton Weather Forecasting Pty Ltd, Nairne, South Australia

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Most research into long and medium range rainfall and crop forecasting in Australia has focused on the El Niño/Southern Oscillation. The Southern Oscillation Index (SOI) has been found to be of limited use in southern Australia for rainfall forecasting in the critical April to October growing season period. In southern Australia during this period one of the more common rain mechanisms is the general uplift in 'northwest cloudbands' which often have their origin in ocean areas to the northwest of the Australian continent. A set of seven model indices were devised using climatic variables which are related to the formation of these 'northwest cloudbands', namely surrogate measurements of upper-level Rossby waves and northeast Indian Ocean sea-surface temperatures and gradients. The indices were formulated from a dependent dataset comprising 27 years of surface pressure and 500 hPa geopotential height from sites mostly about Australia.

These indices were then tested on a further ten years of independent data for correlation with rainfall over part and full growing seasons, and with (de-trended) wheat yields. The results showed significant correlations typically 0.6 to 0.9 over much of southern Australia.

Introduction

Between 1991 and 1994 the annual value of Australia's wheat, barley and other coarse grain production averaged $4 billion (Australian dollars). With all other crops included the production value was $11.4 billion. Further inclusion of livestock products raises the total figure to $23.2 billion (Kreitals et al. 1994). In this continent of high rainfall variability (National Climate Centre 1994) it is clear that much is to be gained from the development of accurate and reliable rainfall and crop yield forecasting models.

Most research into long and medium-range forecasting of rainfall and/or winter crop yield in Australia has focused on the El Niño/ Southern Oscillation (ENSO) or on the Southern Oscillation Index (SOI) (e.g. Drosdowsky and Williams 1991; Stone and Auliciems 1992; Clewett et al. 1995; Rimmington and Nicholls 1993; Scoccimarro et al. 1995). The SOI singly has been found to be of limited use in southern Australia for predicting rainfall in the cereal growing period (April to October). During this period, a common mechanism for rain is the general uplift in northwest cloudbands ahead of cold frontal zones. The formation of the cloudbands appears to be dependent on sea-surface temperatures in the northeast Indian Ocean; the uplift in the cloudbands

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Corresponding author address: Mr I. Holton, Holton Weather Forecasting Pty Ltd, PO Box 728, Nairne, South Australia 5252, Australia.

depends upon the presence and strength of a major long wave anomaly trough over or just west of the Australian continent (e.g. Drosdowsky 1993; Smith 1994; Frederiksen and Balgovind 1993). The Quasi-biennial Oscillation (QBO) affects mean sea-level pressures and 500 hPa geopotential heights, and thereby may contribute to seasonal variability (Hopwood 1972; Trenberth 1975; Ebdon 1975). Most of these factors are used separately, or in combination, in many of the current long and medium range forecasting techniques (Barnston et al. 1994). More recently, the Indonesian throughflow has been shown to play an important role in the meridional transport of heat from the Pacific to Indian Ocean basins (Meyers et al. 1994, Meyers 1996), thereby influencing sea-surface temperatures in the northeast Indian Ocean area.

Palmer and Anderson (1994) point out that a large component of extratropical predictability is of tropical origin via teleconnections induced by Rossby wave dynamics which are generally largest in the winter season. Bye (1992) proposed a 'barocoupling' model in which a Rossby wave in the mixed layer of the ocean couples with a Rossby wave in the divergent barotropic atmosphere. The implication of his model is that weather systems have a seasonal 'memory' resulting from the barocoupling of the previous several months. Bye's model predicts seasonal waves with a growth time-scale of the order of one to two years.

To incorporate all of these climatic concepts into the forecasting models presented here, a selection of surface pressure data and upper-level data were used as surrogates. The SOI itself was also included in several of the models. Thus a suite of potential predictors are available. All the potential predictors were examined with lead times of up to nineteen months from observation to forecast commencement.

The aim of this work was to incorporate suitable predictors into model indices so that these indices might be useful indicators of future rainfall and crop yield – somewhat analogous to the way SOI is often used.

Data

Data for development of the model indices and for (independent) testing were obtained for the 37-year period of 1957 to 1993. The first 27 years were used for development; the remaining ten years for testing. Monthly average mean sea-level (MSL) pressures, recorded at 9 am local time, were obtained for Darwin Airport, Willis Island, Port Hedland and Cocos Island (See Figs 1 and 2 for all locations). Such pressures are considered likely to be linked to the sea-surface temperature. These pressures were then used as two normalised indices: (1) Darwin Airport minus Willis Island; and (2) Cocos Island minus Port Hedland.

Monthly average 500 hPa geopotential heights recorded at 9 am local time were obtained for Port Hedland, Perth Airport and Adelaide Airport. Port Hedland's 500 hPa height was expected to be important as, firstly, a measure of the QBO (following Ebdon 1975) and, secondly, a local measure of the strength of the Southern Oscillation (Drosdowsky and Williams 1991; Palmer and Anderson 1994).

A normalised index of Adelaide minus Perth 500 hPa values was formed on the assumption that this would indicate the formation and movement of long wave Rossby waves (in preferred longitudes for northwest cloudband 'conveyer-belt' upslide).

Around Minnipa on Eyre Peninsula a local farming rule is that 'early season rainfall is a significant forecast indicator of subsequent cereal crop yields in low rainfall districts of the Eyre Peninsula region of South Australia' (private communications, Alan Lymn, farmer of Wudinna, South Australia; Jim Egan and Jacqui Balston of South Australian Research and Development Institute, SARDI). Accordingly, the rainfall over April and May at Minnipa was included as a potential component. Available crop yield data for the period was provided by SARDI.

Component selection and index development

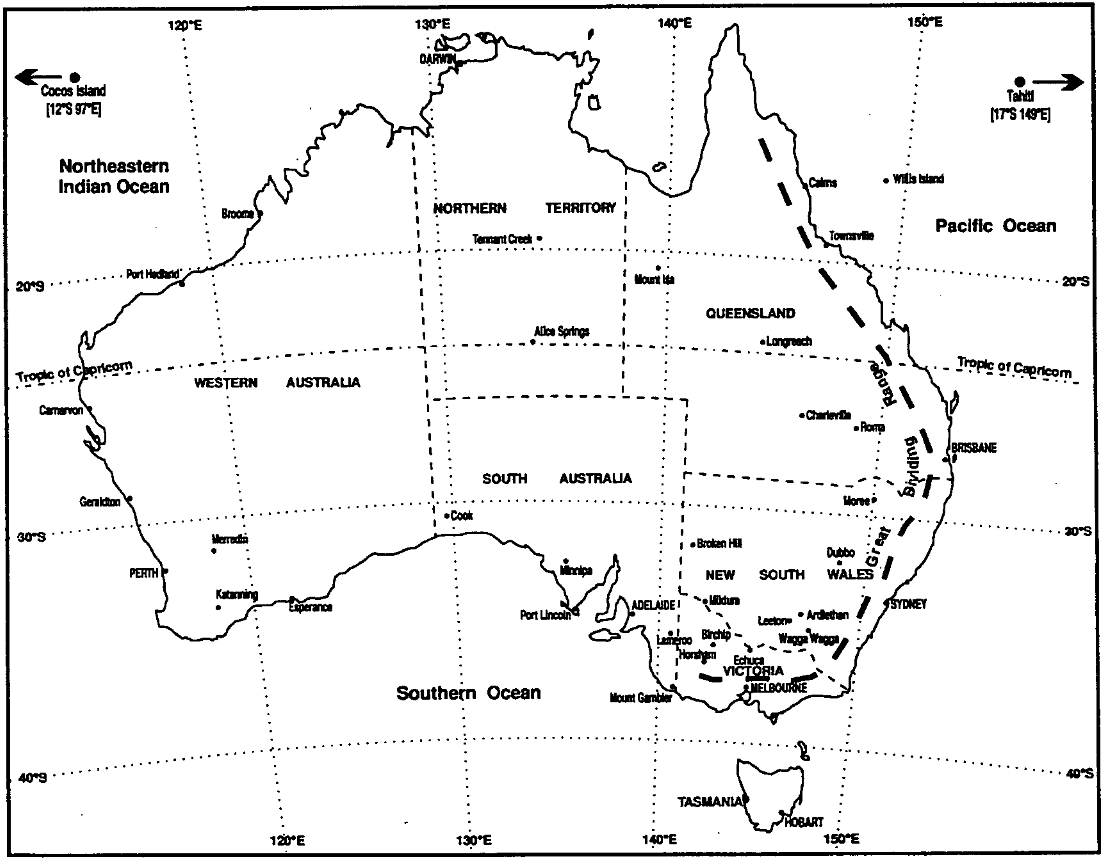
With such a large number of potential components for model indices, it is imperative to retain a useful amount of independent data; generally ten observations or seasons were retained. Initial trial regressions were performed on the base data period of 27 years from 1957 to 1983. One might regard the 'x' values as being the suite of potential predictors or components for the indices; the 'y' values being:

- wheat crop yields at Minnipa Research Centre;
- wheat crop yields at the Hundred of Bews in South Australia;
- wheat crop yields at a property near Ardlethan in NSW;
- total rainfall (mm) during April to October at Minnipa Research Centre; and
- total rainfall (mm) during April to October at Lameroo in South Australia.

The following thirteen variables were found to be the most common and robust predictors:

(1) Darwin minus Willis Island July pressure in previous year (dwjl);
(2) Cocos Island minus Port Hedland January pressure in previous year (chjy);
(3) Cocos Island minus Port Hedland August pressure in previous year (chag);
(4) Cocos Island minus Port Hedland October pressure in previous year (choc);

Fig. 1 Location map (features, states, islands and towns).



(5) Cocos Island minus Port Hedland February pressure in current year (lchfb);
(6) Cocos Island minus Port Hedland March pressure in current year (lchmr);
(7) Port Hedland 500 hPa geopotential height in August of previous year (pedag5);
(8) Port Hedland 500 hPa height in February of current year (lpedfb5);
(9) Port Hedland 500 hPa height in March of current year (lpedmr5);
(10) Port Hedland 500 hPa height in April of current year (lpedap5);
(11) Adelaide Airport minus Perth Airport 500 hPa height in October the previous year (apoc5);
(12) Minnipa Research Centre April 15 to May 15 early season rainfall (mm) (minmmap); and,
(13) Willis Island March pressure minus Alice Springs April pressure (spci). A space-time pressure differential such as this was expected by Bye (1992).

A further two variables were added:

- the Southern Oscillation index of July the previous year (sojl); and
- the Southern Oscillation Index of October the previous year (sooc).

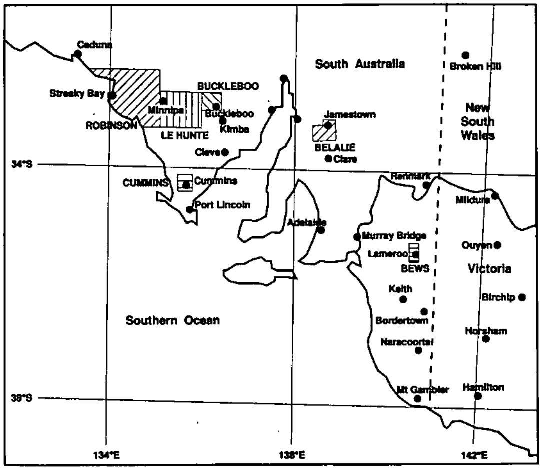
The predictor sojl was also one of two SO indices used by Stone (1996) to forecast rain on a more global scale. The addition of the SOI from the previous year was also prompted by results of Rimmington and Nicholls (1993) who noted previous year SOI was generally superior as a predictor to using current year SOI.

Seven basic indices denoted *H1* to *H7* were derived from the above components, namely:

Index 1: *H1* = apoc5+dwjl-chjy+chag+choc
Index 2: *H2* = apoc5-sojl-sooc
Index 3: *H3* = apoc5-sojl+pedag5-chjy+chag+choc
Index 4: *H4* = apoc5-sojl-chjy+chag+choc
Index 5: *H5* = apoc5+dwjl+chag+choc-lchfb-lchmr
Index 6: *H6* = apoc5+dwjl-chjy+chag+choc+spci
Index 7: *H7* = apoc5+dwjl+chag+lpedfb5+lpedmr5-lpedap5

The indices are simply the sum of the component variables. The 'coefficients' of these variables are always unity. The components of *Hi* were chosen so that *Hi* was well correlated with the predictands, '*y*', men-

Fig.2 Location map (wheat growing hundreds and counties of South Australia)



tioned earlier. The '*H*' values may therefore be regarded as model indices – so that for each of the seven indices, *Hi*, the seasonal rainfall and the crop yields at any location are proportional to the respective value of *Hi*.

As well as the above seven indices, a further seven secondary indices were formed by including early season Autumn rainfall, mid-April to mid-May, at Minnipa. These sub-model indices were simply formed by adding the early Minnipa rainfall in millimetres to *Hi*. Forecasts of the predictands, using indices *H1, H2, H3* and *H4* would in practice be available during early November of the previous year; forecasts using basic *H5* would be available during early April of the current year. Forecasts using *H6* and *H7* would be available in early May of the current year. Predictions using sub-models would be ready for issue in late May of the current year.

Testing of indices: procedure and results

All indices and secondary indices were then tested on the independent data from 1984 to 1993. The essence of the testing was to ascertain whether the (apparently) useful correlations found with dependent data persisted with the independent data. Spatially, the tests were confined to rainfall districts south of the solid black line shown in Fig. 3. This southern area of Australia includes pastoral districts which rely on pasture germination and growth from 'winter season' rainfall, and also covers most of the main wheat, coarse grain, grain legume and oilseed growing regions of the continent (Krietals et al. 1994) (Fig. 4).

During the foregoing tests, the stability of the correlations between model indices and predictands was investigated. Correlations were then subjected to the following stability checks and rejected if the following conditions were not met:

- All base period correlations (27 years, 1957 to 1983) had to be at least 0.3;
- Correlations on ten year periods within the development data (1957 to 1966, and 1974 to 1983) were compared, and the two developmental ten year period correlations had to be within 0.3 of each other and with the 1957 to 1983 period.

Annual rainfalls

Actual rainfall totals for the year (mm) for selected Australian State locations were tested on the *H1, H2, H3* and *H4* models. Predictions based on these four model indices are available at the end of the year prior to the rainfall event. Correlation coefficients are shown in Table 1. Where the correlation test result is less than 0.3, or the correlation was unstable on the dependent data, a blank space is shown. This proviso is applied throughout hereafter.

Table 1. **Correlation coefficients for independent data for total annual rainfall at selected locations with four model indices. Blanks indicate r less than 0.3.**

Site	*H1*	*H2*	*H3*	*H4*
Merredin (WA)		0.37	0.52	0.36
Katanning (WA)	0.55	0.60	0.82	0.72
Minnipa (SA)	0.54	0.30	0.61	0.51
Lameroo (SA)		0.32		
Birchip (Vic)		0.39		
Horsham (Vic)		0.34		
Wagga (NSW)		0.39	0.45	0.35
Dubbo (NSW)				

Apart from Katanning and Minnipa the models had only poor to moderate correlations with the annual rainfall. However, this result was not unexpected, considering that the models were specifically designed to forecast growing season rainfall from April to October and not total annual rainfall. Higher correlations of 0.7 or more were found when using the other indices, (*H5, H6*, and *H7*) but these would not be available until April or May of the year concerned.

Three-monthly rainfall in Districts 18 and 25A

Correlations with seasonal three-monthly rainfall deciles (commencing with each month) were examined in Districts 18 (Western Agricultural, SA), and 25A (Murray Mallee, SA). Correlations of 0.4 to 0.8 were

Fig. 3 Location map (Australian meteorological districts).

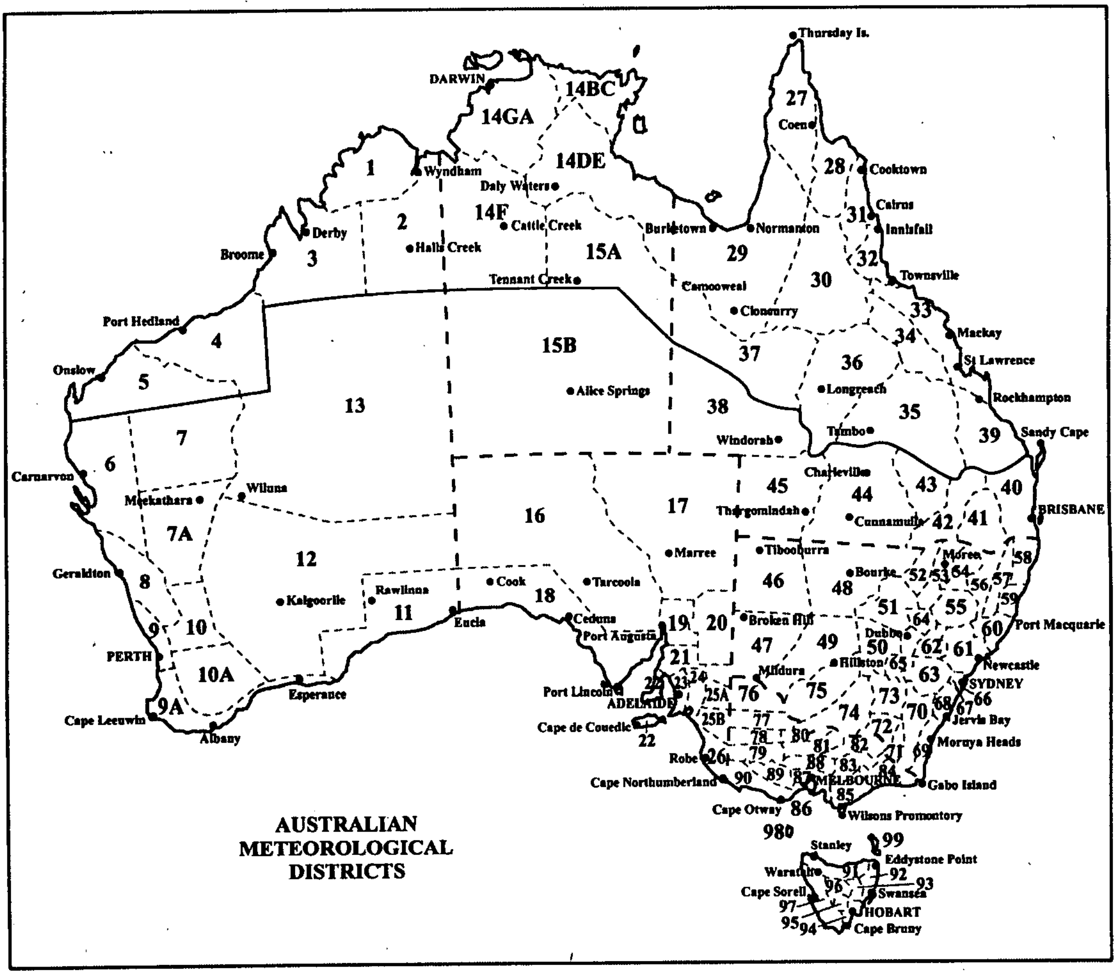
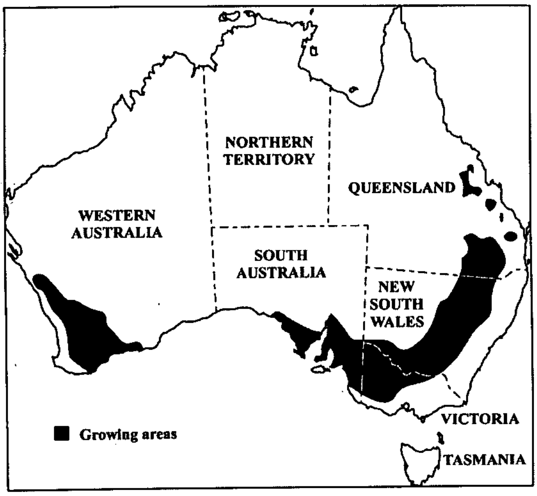


Fig. 4 Location map (Australia's main "winter" grain growing regions)



found for three-monthly rainfalls in July, August and September. The addition of early season rainfall from Minnipa extended the period where correlation results were above 0.4 to include most seasonal three-month periods commencing June to November.

Seasonal rainfall at Minnipa and Lameroo

Actual growing season and part growing season rainfall at Minnipa (SA) and Lameroo (SA) were correlated with model indices. The indices chosen for this test were those that had the best correlations on the dependent data. Marked increases in correlations at both sites were found with the addition of Minnipa early season rainfall, that is, with the secondary indices.

The models were then tested on a measure of total growing season rainfall deciles. This was calculated as half the sum of the decile for the June to August period and the decile for the September to November period.

Table 2. **Correlation coefficients on independent data of best performing model indices available in November and in May with actual seasonal rainfall at Minnipa and Lameroo. Suffix MR denotes model index with early season rainfall at Minnipa added.**

Site/ rainfall period	*Best Nov. index H1*	*Best May index H7*	$H1_{MR}$	$H7_{MR}$
Minnipa				
April to Oct.	0.63	0.73	0.67	0.75
June to Oct.	0.87	0.77	0.94	0.83
July to Oct.	0.69	0.69	0.77	0.75
Aug. to Oct.	0.63	0.73	0.67	0.75
Lameroo				
April to Oct.	0.45	0.76	0.61	0.84
June to Oct.	0.53	0.80	0.69	0.87
July to Oct.	0.52	0.74	0.64	0.80
Aug to Oct.	0.45	0.76	0.61	0.84

Analyses were conducted for Meteorological Districts joined by an line from Roma (QLD) to Dubbo (NSW), to Wagga Wagga (NSW), to Echuca (VIC), to Birchip(VIC), to Lameroo (SA), to Minnipa (SA), to Cook (SA), to Esperance (WA), to Katanning (WA), to Merredin (WA), to Geraldton (WA). These districts generally lie in the middle of the southern Australian cropping belt. The addition of the Minnipa early season rain increased the correlations over some southern New South Wales districts, most Victorian districts, and almost all South Australian rainfall districts (see Table 4).

July to September rainfall deciles

The rainfall decile for the three-month period July, August, September was selected as a predictand since this is an important indicator for winter crops (French and Schultz 1984). This predictand was tested over all meteorological districts for significant correlation with the H indices. For each H index, the r value was plotted at the centroid of each district and then contours drawn subjectively. Figure 5 is a plot using the maximum value of any of the seven indices for each district. Figure 6 is similar again but uses the best performing index modified to include the local early season rainfall in the district.

Wheat yields

Using the ten-year independent dataset, the performance of the indices with regard to wheat yields was investigated. Such a test compared all indices against yearly Hundred or County wheat yields from six South Australian regions, and from a property near Ardlethan in southern New South Wales. All wheat yields were detrended for technological change over time before testing. The addition of a local early rainfall component boosted the correlations significantly (Table 5). Robinson, Le Hunte and Buckleboo clearly responded to the addition of local Minnipa early season rainfall.

Table 3. **Correlation coefficients (r), on independent data, for combined June-August and September-November District rainfall deciles with the indices.**

Models district	*H1*	*H2*	*H3*	*H4*	*H5*	*H6*	*H7*
42							
53							
64							
65	0.49	0.71	0.45	0.65			0.49
73	0.48	0.79	0.45	0.65			0.66
74	0.55	0.69	0.62	0.65	0.53	0.59	0.81
81	0.36	0.75	0.50	0.56		0.42	0.57
80	0.45	0.76	0.68	0.65	0.33	0.57	0.69
77		0.58	0.31				0.54
25b	0.46		0.53	0.56	0.58	0.43	
24	0.59	0.78	0.73	0.71	0.70	0.66	0.84
23	0.57	0.47	0.74	0.58	0.75	0.74	0.77
22	0.80	0.44	0.83	0.82	0.67	0.87	0.77
18	0.90	0.49	0.85	0.85	0.78	0.90	0.83
11	0.63	0.54	0.59	0.69	0.55	0.59	0.70
9a			0.56	0.39	0.53	0.42	0.32
10a	0.35				0.62		0.57
10			0.43	0.40	0.33		0.56
8			0.46	0.44	0.40		0.56

Table 4. Correlation coefficients on independent data for combined June-August and September- November district rainfall deciles with secondary indices which include a component for early season rain at Minnipa.

Index	$H1_{MR}$	$H2_{MR}$	$H3_{MR}$	$H4_{MR}$	$H5_{MR}$	$H6_{MR}$	$H7_{MR}$
District 74	0.65	0.84	0.68	0.75	0.62	0.61	0.84
81	0.42	0.82	0.52	0.75	0.30	0.42	0.59
80	0.57	0.90	0.72	0.59	0.45	0.60	0.73
77	0.34	0.75	0.44	0.49	0.33	0.39	0.63
25b	0.53	0.83	0.57	0.62	0.61	0.45	0.83
24	0.67	0.91	0.76	0.78	0.75	0.66	0.86
23	0.76	0.72	0.84	0.81	0.87	0.80	0.87
22	0.85	0.63	0.85	0.88	0.73	0.83	0.81
18	0.90	0.63	0.84	0.88	0.80	0.82	0.84

Fig. 5 **Maximum correlations from all base models with July to September decile rainfall.**

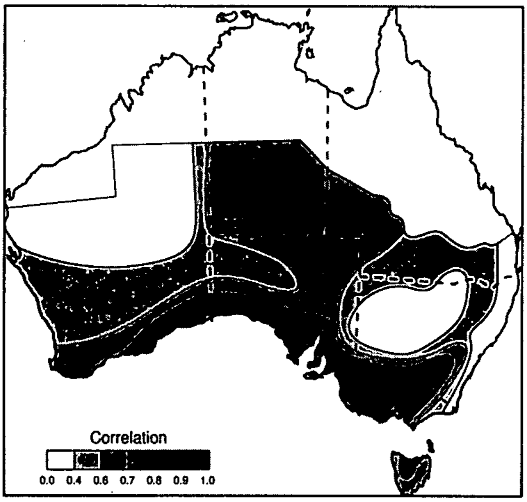
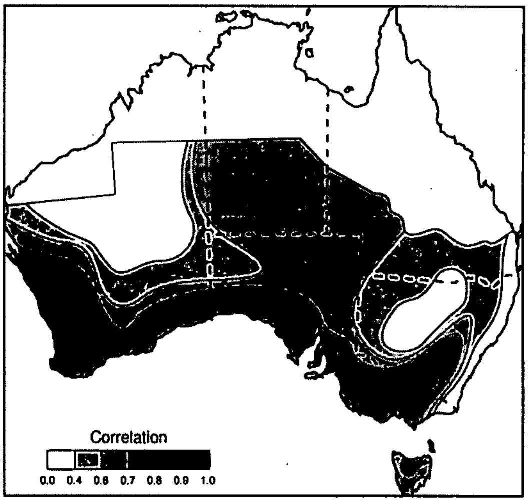


Fig. 6 **Maximum correlations from all models with the addition of local autumn early season rainfall for the July to September decile rainfall.**



Bews responded strongly to the addition of local Lameroo early season rainfall; Ardlethan responded to a lesser extent to the addition of local Leeton early season rainfall. The higher rainfall Hundred of Cummins, which can suffer from waterlogging and subsequent reduction in yield, responded to the addition of Leeton early season rainfall. In contrast to the other tested wheat yields, the Hundred of Belalie had a negative response to any addition of early season rainfall. Notably, when Cummins yield was tested with indices including local Cummins April to May rainfall, and Belalie with local Jamestown April to May rainfall, neither showed any improvement in correlation.

A final test with the indices was undertaken with (detrended) total Australian wheat yield for the combined 34-year period from 1957 to 1990. Although it is noted that this dataset is not independent, it is a worthwhile constancy check. The indices had correlation coefficients as shown in Table 6. By comparison, the correlation coefficient for SOI from previous July, as used by Stone (1996), was -0.31.

Rossby wave linkage

The increase in skill due to the inclusion of early season rainfall at Lameroo on WA sites may be explained by the retrogression of Rossby wave long-wave patterns westwards at these latitudes. The 'barocoupling' model of Bye (1992) predicted wave speed,of 10 m/s eastwards at 45°S, reducing to 2 m/s at 35°S. Data presented here appears to show a further reduction in wave speed as one progresses northwards. Rossby wave activity for each month from July 1994 to August 1996 at various

Table 5. **Correlation coefficients on independent data for wheat yield with model indices.**

Index Site, Hundred or County	H1	H2	H3	H4	H5	H6	H7
County of Robinson (SA)	0.80	0.67	0.59	0.60	0.84	0.63	
County of Le Hunte (SA)	0.64	0.51	0.43		0.75	0.47	
Hundred of Buckleboo (SA)	0.60	0.54	0.50		0.71	0.42	
Hundred of Cummins (SA)	0.43	0.63	0.41	0.44	0.63	0.44	0.42
Hundred of Bews (SA)	0.49	0.43					
Hundred of Belalie (SA)	0.64	0.60	0.63	0.72	0.61	0.53	0.61
Ardlethan (NSW)		0.46	0.40	0.42	0.44	0.31	0.40
Index with early season rainfall at Minnipa	H1	H2	H3	H4	H5	H6	H7
Site, Hundred or County							
County of Robinson (SA)	0.91		0.76	0.83	0.72	0.85	0.75
County of Le Hunte (SA)	0.85		0.68	0.74	0.72	0.84	0.64
Hundred of Buckleboo (SA)	0.78		0.67	0.74	0.39	0.78	0.59
Model with early season rainfall at Lameroo	H1	H2	H3	H4	H5	H6	H7
Site, Hundred or County							
Hundred of Bews (SA)	0.85	0.85	0.90	0.87	0.83	0.84	0.86
Model with early season rainfall at Leeton	H1	H2	H3	H4	H5	H6	H7
Site, Hundred or County							
Hundred of Cummins (SA)	0.52	0.55	0.52	0.51	0.52	0.52	0.56
Ardlethan (NSW)	0.36	0.69	0.59	0.60	0.51	0.52	0.61

Table 6. **Correlation coefficients for combined period 1957-90 for Australian wheat yield against model indices.**

H1	H2	H3	H4	H5	H6	H7
0.67	0.60	0.74	0.67	0.69	0.69	0.62

longitudes was compared. Monthly Rossby activity was measured at a location from a daily assessment of whether the 500 hPa flow in a grid box was trough-dominated or ridge-dominated. The monthly total number of trough-dominated days minus the ridge-dominated days was then taken as the monthly Rossby Wave activity. A grid box was assigned to each longitude so that the grid box assigned to 115°E covered 25° to 30°S and 110° to 120°E and so forth. For grid boxes at 115°E, 125°E etc., a time series for Rossby Wave activity at longitudes is shown at Fig. 7. At 25°S to 30°S the 500 hPa maxima and minima of the activity appear to retrogress westwards at a speed of approximately 0.5 m/s in the Australian region. This would allow for a lag from Lameroo in SA to the general Merredin/Geraldton area (WA) of approximately two to three months. Interactions between westward drifting long-waves at 25°-30°S, and eastwards drifting short and long waves at 35°S would provide rainfall connections via north-west cloudband events.

Predictor components over the whole 37-year period of available data are in the main only weakly correlated with each other. There are some stronger negative correlation connections (0.5 to 0.6) between the Port Hedland geopotential height and the SOI during February to May just prior to, or during, the early part of the growing season. This connection is also shown at Fig. 8 which shows the Rossby wave activity to be linked to the SOI. The indices do not use SOI from this time of year, however. The only other higher correlation between predictor components is that between the SOI in July and the Darwin minus Willis Island MSL pressure difference in July (r = 0.6). These two input variables share a common

Fig. 7 Rossby wave activity at 25°S to 30°S (Offsets –15, 0, +20, +30 for 115°E, 125°E, 135°E and 145°E respectively)

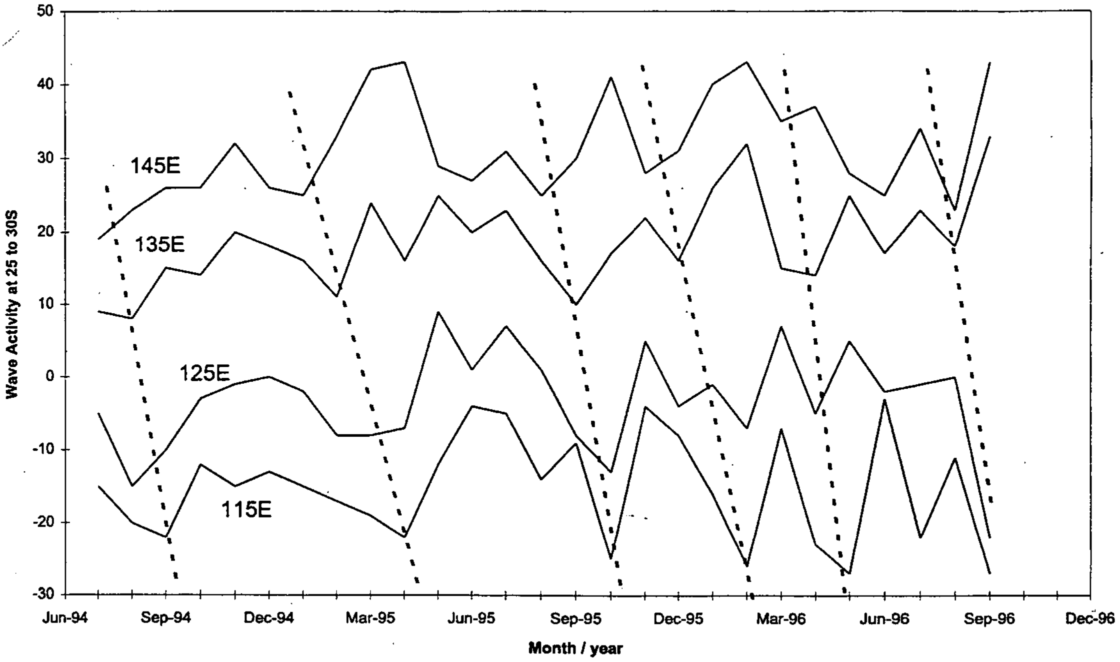
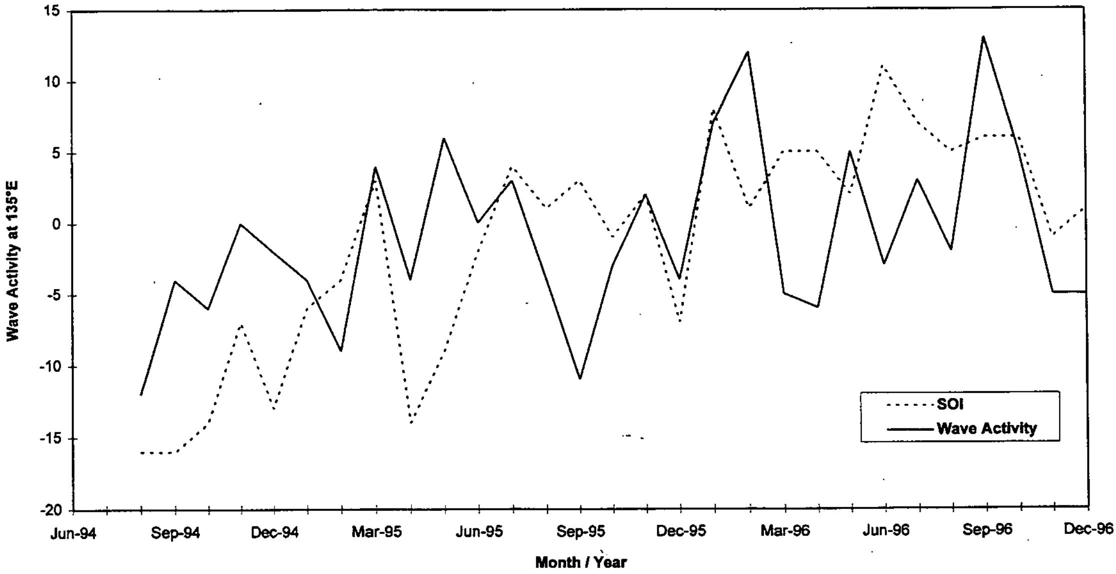


Fig. 8 SOI and Rossby wave activity.



pressure variable (viz. Darwin) and this higher correlation was expected. Therefore, they were not included together in any of the model indices.

Discussion

A reviewer has pointed out that there is a well-recognised persistence in rainfall anomalies during the typical ENSO year, that is from May to the following autumn. Therefore such persistence would partially explain the positive influence of the inclusion of Minnipa's early season rainfall (15 April to 15 May) on the correlations between the secondary indices and the rainfall over South Australian and some Victorian districts. The addition of early season Katanning and Leeton rainfall did not have any positive effect on any of the rainfall correlation results.

The results of tests on the wheat yields were most encouraging, with most yield versus index correlations responding markedly to the addition of the local early season rainfall. Crop germination and early growth respond to early season rainfall and consequent soil moisture (French and Schultz 1984). Therefore it is not surprising to see such a marked increase in the yield correlations with the addition of this factor. This supports the 'rule' of local early season autumn rainfall being a useful indicator of final crop yields over much of southern Australia. The lack of response to early season rainfall in the Belalie Hundred wheat yield analysis may be a result of the high clay content of soils in the Belalie district. The non-porous nature of the soils in the district results in less benefit from the early season rainfall. Therefore, a much higher rainfall amount is needed to achieve the 'break in the season' in the Belalie district than is required on lighter soils of South Australia.

Correlation coefficients, r, for most models reached 0.6 to over 0.9 across much of the wheat growing areas of southern Australia. For each district, a value of r was assigned to the centre and then isopleths drawn subjectively. These results are accepted at the three per cent (or less) significance level. Large parts of the wheat growing areas of eastern South Australia, Victoria, and parts of southern New South Wales consistently scored

Fig. 9 **Forecast vs actual decile rainfall May to July plus August to October, District 18, Western Ag. S.A. All forecast regression coefficients calculated from 1957 to 1983 data.**

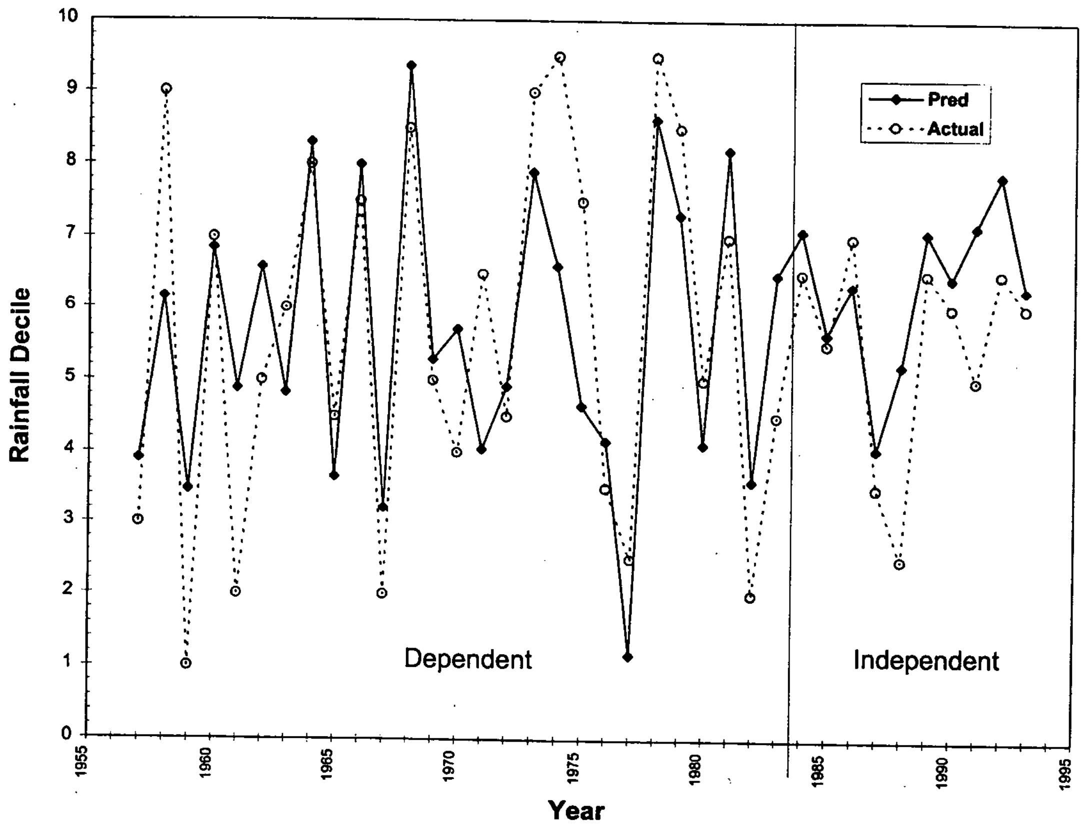
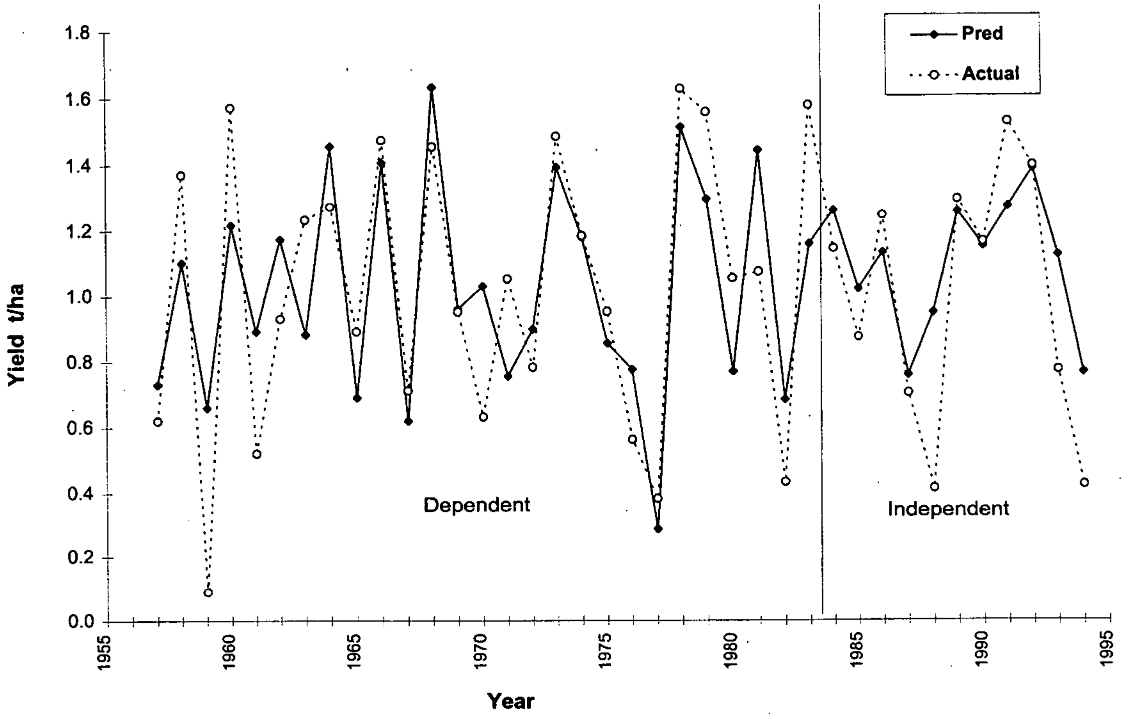


Fig. 10 Forecast vs actual County Robinson annual wheat yield. All forecast regression coefficients calculated from 1957 to 1983 data.



correlations of 0.8 to over 0.9. These results are accepted at a one per cent or less significance level. In contrast, over much of central Western Australia, central and northern New South Wales, and southern Queensland the models correlated below 0.6. Over much of South Australia, and over a small part of central western Victoria, small increases in r were obtained by using the secondary indices (that is, the indices which include Minnipa early season rainfall).

Correlations of rainfall and indices drop dramatically to the east of the Great Dividing Range. This suggests that the Range effectively acts as a barrier to rainfall which originates from a westerly direction, and in turn supports the contention that the indices have indeed captured some aspect of the underlying physical relations.

Multiple linear regression techniques may further improve some of the correlation results. However, by formulating the indices in the very simple manner described, the implied forecasting system becomes very flexible and user-friendly. The index can be regarded as a forecast model for rainfall and/or wheat yield at specific sites or districts, by simple regression of the model indices with relevant predictands (see examples Figs 9 and 10).

Conclusions

Seven indices were devised from 27 years of data from 1957 to 1983. These indices were found to have moderate to high correlations of 0.6 to over 0.9 (significant at the 3% to 1% or less level) on an independent ten year period from 1984 to 1993 against: July to September rainfall, growing season rainfall (April to November), and part growing season rainfall (various periods).

These findings were applicable to the main cropping regions of southern New South Wales, Victoria, Tasmania, South Australia and Western Australia. Wheat yields at several Hundreds and Counties of South Australia, and at one farm site in southern new South Wales, also correlated well with the model indices. The addition of early season rainfall (April and May) from Minnipa to the basic indices tended to improve the above correlations, especially those for the crop yields in the South Australian and western Victorian cropping districts. Some Western Australian areas showed a marked increase in correlations when Lameroo's early season rainfall was included in the indices.

The indices would in practice be available in the early part of the growing season if not well before. They were shown to have useful correlations with rainfall and wheat yield over large areas of southern Australia. The testing was on independent data albeit of limited extent, namely ten years.

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